A HELICAL ANTENNA AT K BAND

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PREFACE

The work presented in this paper was done at the Bendix Aviation Corporation Research and Development Laboratories in Detroit, Michigan during the period from 3 January to 15 March 1955. It was done to fulfill a need of the company for a test receiving antenna having almost circular polarization. Specific requirements were set forth concerning bandwidth, beamwidth and axial ratio. The structure had to be small and capable of withstanding an acceleration of 500g. It was felt that a helical antenna might best meet these demands.

The author wishes to express his gratitude for the kind assistance and suggestions given him by I. Rudolph and J. Cheal of Bendix Aviation Corporation and by Professor J. Chaney of the U. S. Naval Postgraduate School. The author also wishes to acknowledge the cooperation of the American Institute of Physics for permission to reproduce Figures 3, 4, and 5 as well as of the McGraw-Hill Book Company, Inc. for permission to reproduce Figure 6.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TABLE OF SYMBOLS

A	-axial length of helix $= nS$
a	-radius of helical conductor
A.R.	-axial ratio of polarization ellipse
C	-circumference of helix $= \pi D$
c	-velocity of light
D	-diameter of helix (center to center)
d	-diameter of helical conductor
E_L	-left-hand circularly polarized wave
E_R	-right-hand circularly polarized wave
G	-ground plane diameter
g	-distance of helix proper from ground plane
k	$- \omega \sqrt{\mu \epsilon}$
L	-helical length of one turn
n	-number of turns
p	-phase velocity factor $= v/c$
R	-radiation mode designation
S	-spacing between turns (center to center)
T	-transmission mode designation
v	-phase velocity of wave propagating along helical conductor
VSWR	-voltage standing wave ratio

α -pitch angle of helix $= \arctan S/\pi D$

β -beamwidth between half-power points

ϵ - dielectric constant of medium

λ -wavelength, when used as a subscript signifies
           the dimension is measured in wavelengths

μ -permeability of medium

ω $-2\pi \times$ (frequency)

CHAPTER I

INTRODUCTION

Within the past decade the helical antenna has been de-
veloped and employed in communications applications for the
amateur and television bands of the frequency spectrum. The
radiation pattern of a helix possesses elliptical polarization
generally, but the antenna can be made to radiate circularly
polarized waves by proper choice of dimensions. The antenna's
physical configuration is relatively small and easy to con-
struct, the dimensions not being too critical. The feed is
simple, directivity good, and terminal impedance relatively
constant over a reasonable wide bandwidth. Helical antennas
have been constructed having a bandwidth ratio of 1.7 to 1.0
/10_7. Matching problems are not too difficult generally.
The foregoing properties make the helical antenna a **very** de-
sirable one for many applications. The symbols used to de-
scribe the helix are given in Figures 1 and 2.

Because of these desirable characteristics of the helical
antenna, particularly the broadband operation and circular
polarization, it was believed that it might be gainfully em-
ployed at the microwave region of the spectrum. The purpose
of this paper is to investigate this possibility and specif-
ically to determine if a helix is a practical radiator at K
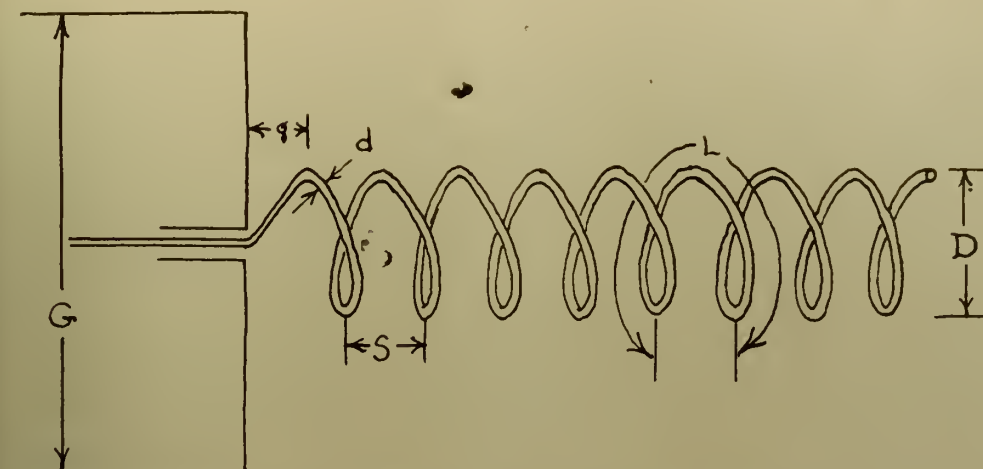
D - diameter of helix (center to center)
d - diameter of helix conductor
C - circumference of helix
G - diameter of ground plane
g - distance from ground plane to first turn of helix
L - length of one turn
n - number of turns
S - spacing between turns (center to center)
∝ - helix pitch angle

Figure 1. The Helical Antenna and Associated Dimensions
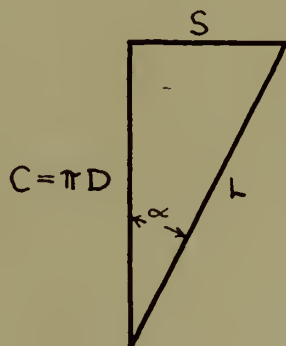
Figure 2. Relation between C, S, L, and ∝ of the Helix

band.

The first few chapters of the paper will be devoted to
a general discussion of the helical antenna and its character-
istics as well as a summary of design data available to date.
The remaining chapters will deal with the particular problem
of obtaining at K band a helical antenna whose general char-
acteristics are not distorted from those at lower frequencies
and the technique employed to obtain the results.

CHAPTER II

GENERAL PROPERTIES OF THE HELICAL ANTENNA

The helix is a familiar geometric form which has been
used extensively in electrical circuits as an inductor. An-
other of its applications is in the traveling-wave tube where
it is employed because of its inherent ability to delay the
propagation of an electromagnetic wave. More recently it
has been applied to the antenna field.

In considering the helix as an antenna, it is advanta-
geous to regard it as a basic type of which the loop and
straight-wire antennas are special cases, rather than as a
unique form of its own. Thus, a helix collapses to a loop,
as the pitch angle of the helix becomes zero. Similarly,
as the pitch angle is increased to ninety degrees, the an-
tenna becomes a linear conductor.

On the helix, transmission and radiation modes exist
and are used to describe particular propagations. The trans-
mission mode defines electromagnetic wave propagation along
an infinite helix which constitutes an infinite transmission
line or waveguide. The radiation mode is employed to de-
scribe the far field pattern of a finite helix.

For a helix of given dimensions, several transmission
modes are possible depending on the frequency. At the lowest

frequency the lowest transmission mode, designated as T_0,
occurs. This mode has adjacent regions of positive and nega-
tive charge separated by many turns and is the important mode
for traveling-wave tubes. An appreciable axial component of
electric field is present in this mode, and this interacts
with the electron stream of the traveling-wave tube. It is
possible for a helix excited in the T_0 transmission mode to
radiate. When this occurs, the normal radiation mode, $T_0 R_0$,
results. In the normal mode the radiation field is a maximum
in a direction perpendicular to the helix axis and is almost
circularly polarized over a limited frequency range. At other
frequencies the polarization varies from elliptical to linear.
This mode has been described mathematically by Wheeler $\angle 16 \underline{7}$.
Figure 3 $\angle 12 \underline{7}$ shows the curve on which the polarization el-
lipse becomes a circle. This condition is obtained when

$$D = (2S)^{\frac{1}{2}}/\pi .$$

The dimensions of the helix must be small compared to the
wavelength, and therefore this mode is not desirable for this
investigation due to the extreme small size involved.

As the frequency is increased to the point where the
circumference of the helix is on the order of one wavelength,
the T_1 transmission mode occurs. For small pitch angles, the
helix has adjacent regions of positive and negative charge
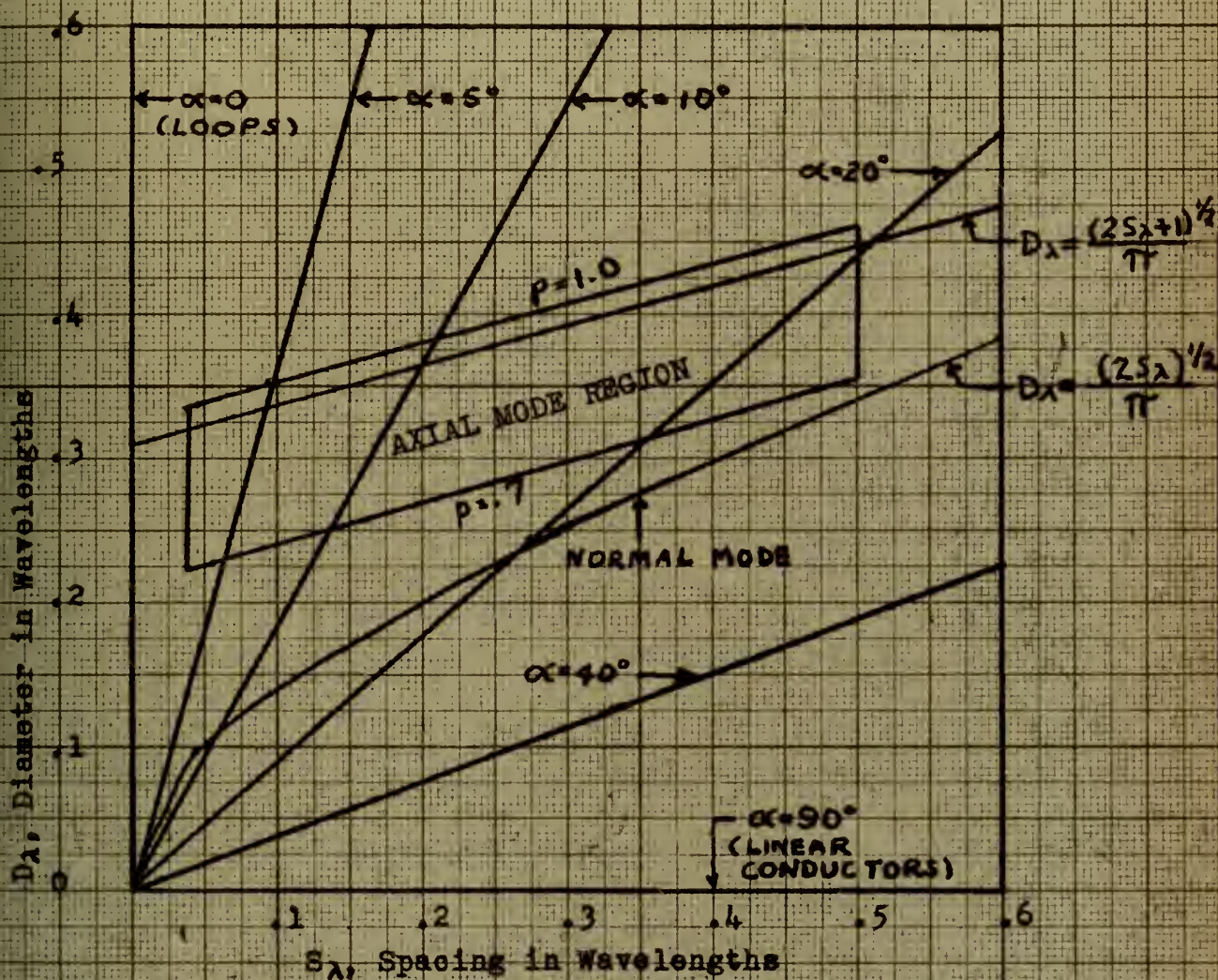separated by about one-half turn. Thus at a given instant,

5

Figure 3. Diameter-spacing Chart for the Helix Showing the Dimensions for Various Radiation Modes (Courtesy of the American Institute of Physics)

adjacent current elements are in phase and so contribute to
give a finite field at a distance. This is the T_1R_1 mode,
commonly called the axial, or beam, mode of radiation and
occurs when the helix circumference is about one wavelength.
The axial mode has its maximum radiation field along the
helix axis, and it can be made almost circularly polarized
over a relatively wide bandwidth by proper choice of dimen-
sions. This mode is also shown in Figure 3, and is defined
approximately near its upper limit by the curve

$$D = (2S \neq 1)^{\frac{1}{2}}/\pi .$$

It is bounded by a region in which the relative phase velocity,
p, varies from 0.7 to 1.0 as is indicated on the curve. It is
this mode which is of particular interest to this investigation.

In discussing the properties of the helical antenna, one
must consider the current distribution along the helix. Meas-
ured current distributions for the normal and axial modes of
radiation are given in Figure 4. When the circumference of
the helix is less than about two-thirds wavelengths, the cur-
rent distribution is nearly sinusoidal as on a long, straight
antenna and produces the normal radiation mode. However,
when the circumference is on the order of one wavelength, the
measured current distribution is relatively uniform over the
middle portion of the helix. By assuming there are two out-
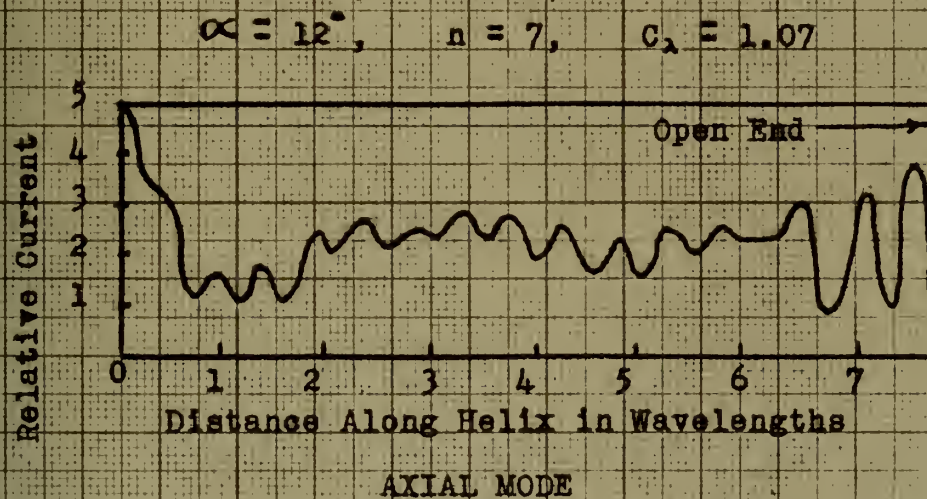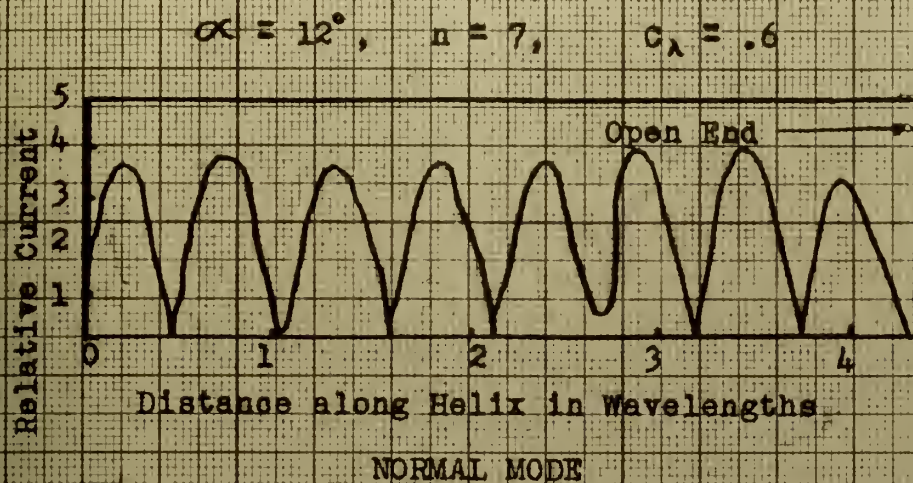ward traveling waves of different phase velocities, one (1)

Figure 4. Measured Current Distributions on Helices
(Courtesy of the American Institute of Physics)

attenuated and the other (2) constant, and two smaller return-
ing traveling waves (3 and 4), as shown in Figure 5, J.A.
Marsh /13_7 has been able to account for the axial mode cur-
rent distribution shown in Figure 4. This type of distribu-
tion is generally characteristic of a helix radiating in the
axial mode.

Referring to Figure 5, there are four waves considered.
Those numbered 1 and 2 travel towards the open end. Wave 1
is exponentially attenuated and is of the T_o mode, while wave
2 is propagated with little or no attenuation and is of the
T_1 mode. At the open end wave 2 is reflected giving rise to
waves 3 and 4 in the reverse direction, wave 4 (T_1 mode) being
constant and wave 3 (T_o mode) exponentially attenuated. In
determining the standing wave ratio, since wave 4 is less in
magnitude than wave 2, the current minima are not zero in the
middle region of the helix. The SWR may be taken as /12_7

$$SWR = \frac{I_2 + I_4}{I_2 - I_4},$$

where the I's are the currents associated with each wave.
Since I_2 is greater than I_4, and I_3 and I_1 are confined to
the ends of the helix, it is possible to calculate the approx-
imate radiation pattern of a long helix on the assumption that
only a single traveling wave (2) is present. This radiation
pattern calculation has been developed and presented by Kraus
/12_7. Kornhauser /4_7 has derived a rigorous expression for
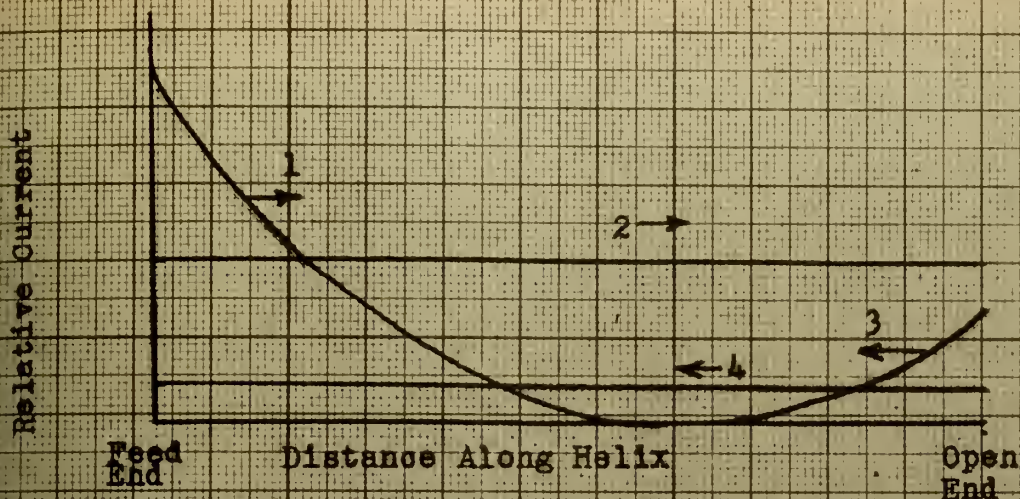
9

Figure 5. Resolution of Current Distribution on Helix Radiating in the Axial Mode (Courtesy of the American Institute of Physics)
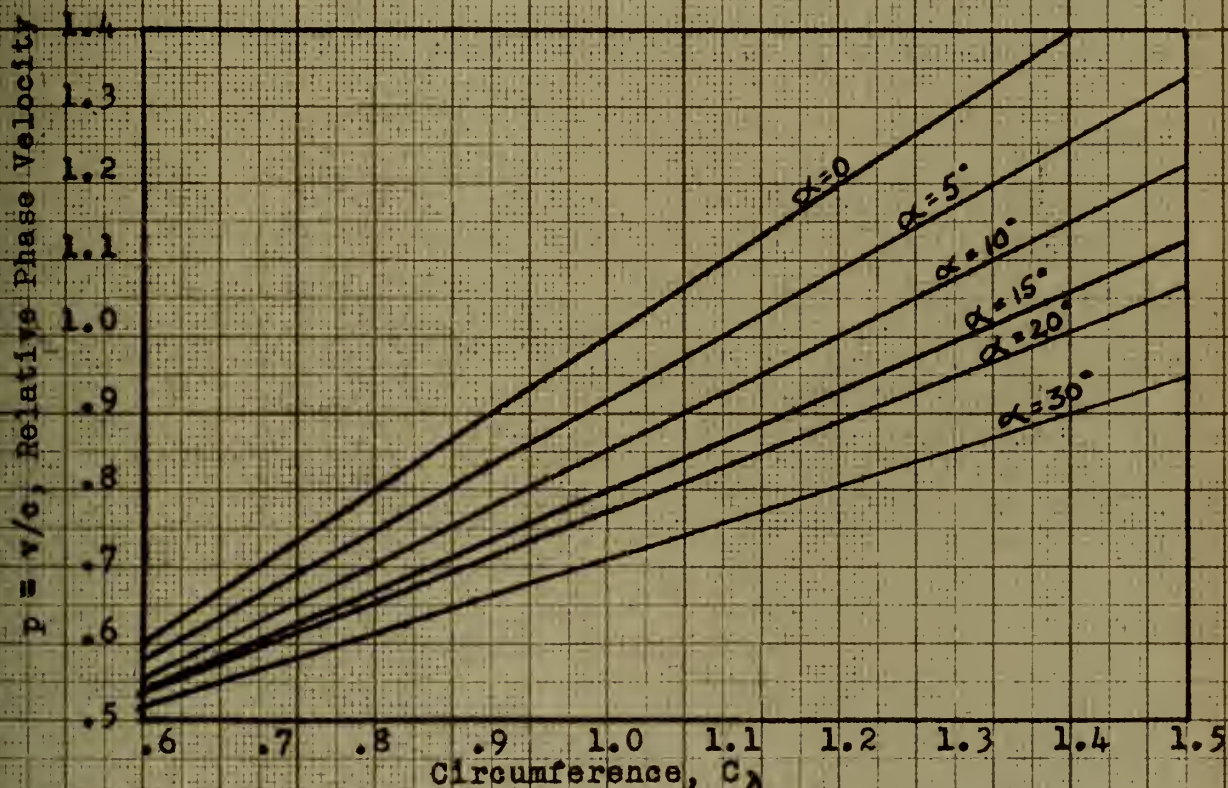

Figure 6. Relative Phase Velocity, p, for Different Values of Pitch Angle, α, as a Function of Circumference, C_λ, for the Condition of In-Phase Fields in the Axial Direction. (Courtesy of McGraw-Hill Book Co., Inc.)

10

the radiation field presuming this same current distribution. This expression, though somewhat more complex than that of Kraus, is at least more complete and applicable to helices of integral or non-integral numbers of turns. In both cases the approximate current distribution of a single traveling wave seems somewhat unrealistic in that the boundary conditions at the ends of the wire cannot be satisfied. Also the effect of the ground plane is always neglected. However, both of these expressions provide means of calculating the patterns which are very close to those observed experimentally.

When the helix radiates in the axial mode, the phase velocity of wave propagation on the helix adjusts itself so as to make the component electric fields from each turn of the helix add nearly in phase in the direction of the helix axis. The phase velocity variation is shown in Figure 6 $\boxed{5}$. This self adjustment of the phase velocity accounts for the persistence of the axial mode radiation pattern over a relatively wide frequency range. The relative phase velocity, p, for the axial mode radiation is given by the expression $\boxed{8}$

$$p = \frac{L_\lambda}{S_\lambda + 1}.$$

This expression for in phase fields is referred to as the condition of maximum directivity. Kraus $\boxed{9}$ has presented a helix theorem which states:

When the circumference of an axial or end-fire helix
is about one wavelength (T_1 transmission mode dominant)
there is a band of frequencies over which the phase
velocity of wave propagation on the helix tends to-
wards a value that makes the directivity a maximum.

Figure 3 is the diameter-spacing chart for the helix showing

relative dimensions in wavelengths for the normal and axial

modes. The axial mode region may be seen to extend over a

relatively large range.

From symmetry it appears that when one traveling wave is

present on a long helix, the radiation in the direction of the

axis is circularly polarized. Consider a traveling wave on

a helix whose circumference is approximately one wavelength.

At a given instant of time regions of positive and negative

electric charge appear at opposite ends of a diameter. As

time proceeds these regions of charge travel along the helix,

causing the field to rotate, making one revolution per cycle.

Thus on the axis of the helix circular polarization is ob-

served.

The ratio of the major to the minor axis of the polar-

ization ellipse of the electric field intensity is by defi-

nition the axial ratio. An axial ratio of one means circular

polarization, whereas an infinite axial ratio denotes a plane

polarized wave. Circular polarization requires two relations

between the crossed fields in a wave. They must be of equal

intensity and in phase quadrature. The direction of rotation

of the polarization depends on the phase sequence of the
crossed components of either field. Polarization is right
or left-handed depending on the direction in which the helix
is wound. Kraus $\boxed{8}$ has shown the conditions for circular
polarization on the axis of the helix in the axial mode.
With

$$k = L_\lambda(\sin\alpha - \frac{1}{p}),$$

for any pitch angle between zero and ninety degrees, and a
large number of turns, which are not necessarily an integral
number, nearly circular polarization occurs if k is nearly
plus or minus one. Since $\sin\alpha \leqq 1$ and $\frac{1}{p} \geqq 1$, k is negative
for the axial mode region. Thus p must be given by

$$p = \frac{L_\lambda}{S_\lambda + 1},$$

for circular polarization on the axis. This may be seen to
be the same expression as for in phase fields given above.

If the axial ratio in the direction of the axis is
greater than one, it indicates the presence of other travel-
ing waves on the helix which produce a circularly polarized
component with an E-vector rotation opposite to that of the
principal component. The observed axial ratio is usually
greater than one. Referring once again to Figure 5, and
confining the discussion to the constant waves 2 and 4, the
phenomenon may be explained by assuming that each wave prop-
agates oppositely polarized circular fields, wave 4 being
opposite to 2 and smaller by a reflection process. The pres-

13

ence of two circularly polarized waves is derived from the
field equations .in Appendix I.

The axial ratio of an elliptically polarized field is
composed of two oppositely polarized circular components and
may be expressed by $\underline{/12\_}/$

$$A.R. = \frac{E_R \not{} E_L}{E_R - E_L},$$

where E_R is a wave circularly polarized in a right hand dir-
ection and E_L is in a left hand direction. Wave E_R is assumed
to result from wave 2, the largest in magnitude, and E_L from
wave 4. Thus it would appear that circularity is improved as
the magnitude of the reflected wave is reduced.

CHAPTER III

DESIGN OF THE HELICAL ANTENNA

A helix may be easily excited in the axial mode in a variety of arrangements. The simplest method is by connecting one end of the helix to the inner conductor of a coaxial line at a point where the outer conductor of the line is terminated in a ground plane of sufficient diameter. This ground plane may be flat as shown in Figure 1, or may be conical or parabolic in shape to focus the radiated beam. In the beam mode of operation the axial component of the electric field is substantially zero along the helix axis which permits placing a conductor along the axis with little change in characteristics. The folded helix employs two helices wound in opposite directions, connected in series, and placed side by side with one helix terminated at the ground plane. Another variation is the double layer helix in which two helices of unequal diameters and opposite screw directions are placed with coincident axes and connected in series, with the outer helix terminated in the ground plane. Other helices employ variable pitch, variable spacing, or tapered diameter to obtain a better axial ratio. However all of the above described arrangements, except the one shown in Figure 1, are difficult to manufacture, particularly at microwave frequencies. There-

15

fore discussion will be limited to the simple, uniform helix.

In determining the dimensions to be used in designing the helix, certain factors must be taken into consideration. The beamwidth, gain, and axial ratio are interdependent. The gain is directly proportional to the number of turns of the helix, n, whereas the beamwidth is inversely proportional to the square root of n. The axial ratio may be shown to be given approximately by the expression $\boxed{5}$

$$A.R. = \frac{2n \neq 1}{2n},$$

when the relative phase velocity on the helix is such as to fulfill the maximum directivity condition.

On the basis of experimental data, the following dimensions are presented $\boxed{5}$ as affording small side lobes, a sharp pattern, and little radiation resistance variation over the bandwidth. The symbols refer to those used in Figure 1, and the wavelength is based on the center frequency.

$$
\begin{aligned}
D &= 0.32\,\lambda \\
S &= 0.22\,\lambda \\
C &= 1.00\,\lambda \\
g &= 0.12\,\lambda \\
G &= 0.80\,\lambda \\
d &= 0.02\,\lambda
\end{aligned}
$$

Empirical formulae have been presented $\boxed{5}$ to calculate gain, terminal impedance, and beamwidth. The beamwidth between half power points, β, is given by

$$\beta = \frac{52}{\frac{C}{\lambda}\sqrt{\frac{nS}{\lambda}}},$$

16

and the power gain with respect to an isotropic circularly
polarized source by

$$\text{Gain} = 15(C_\lambda)^2 n S_\lambda.$$

As long as n is greater than three, α is between 12 and 15
degrees, and C lies between 3/4 and 4/3 wavelengths, the
terminal impedance is nearly pure resistance and is given by

$$R = 140\ C_\lambda \text{ ohms.}$$

CHAPTER IV

MEASUREMENT TECHNIQUES

Before proceeding to the discussion of the helical an-
tenna at K band, it might be best to explain how the measure-
ments discussed are made. Figure 7 shows a block diagram of
the equipment used to measure the antenna's characteristics.
The oscillator employed is a V-90 klystron. A slotted line
is used to measure the VSWR in the waveguide. The helical
antenna is set over the center of a horizontal arm having
a swing of almost 360 degrees. The pick-up horn, mounted
on this horizontal arm, is directly on axis with the helix and
can be moved about a vertical axis to any angle in a hori-
zontal plane at a constant radius from the end of the an-
tenna. The pick-up horn itself can be rotated through 360
degrees on a horizontal axis. These two degrees of rotation-
al freedom for the pick-up horn permit the taking of data
from which the axial ratio and the radiation pattern may be
obtained.

For field pattern measurements of greater accuracy,
an anechoic chamber is used. The transmitting horn is
stationary in the same horizontal plane as the receiving
helical antenna. The helix can be rotated in a horizontal
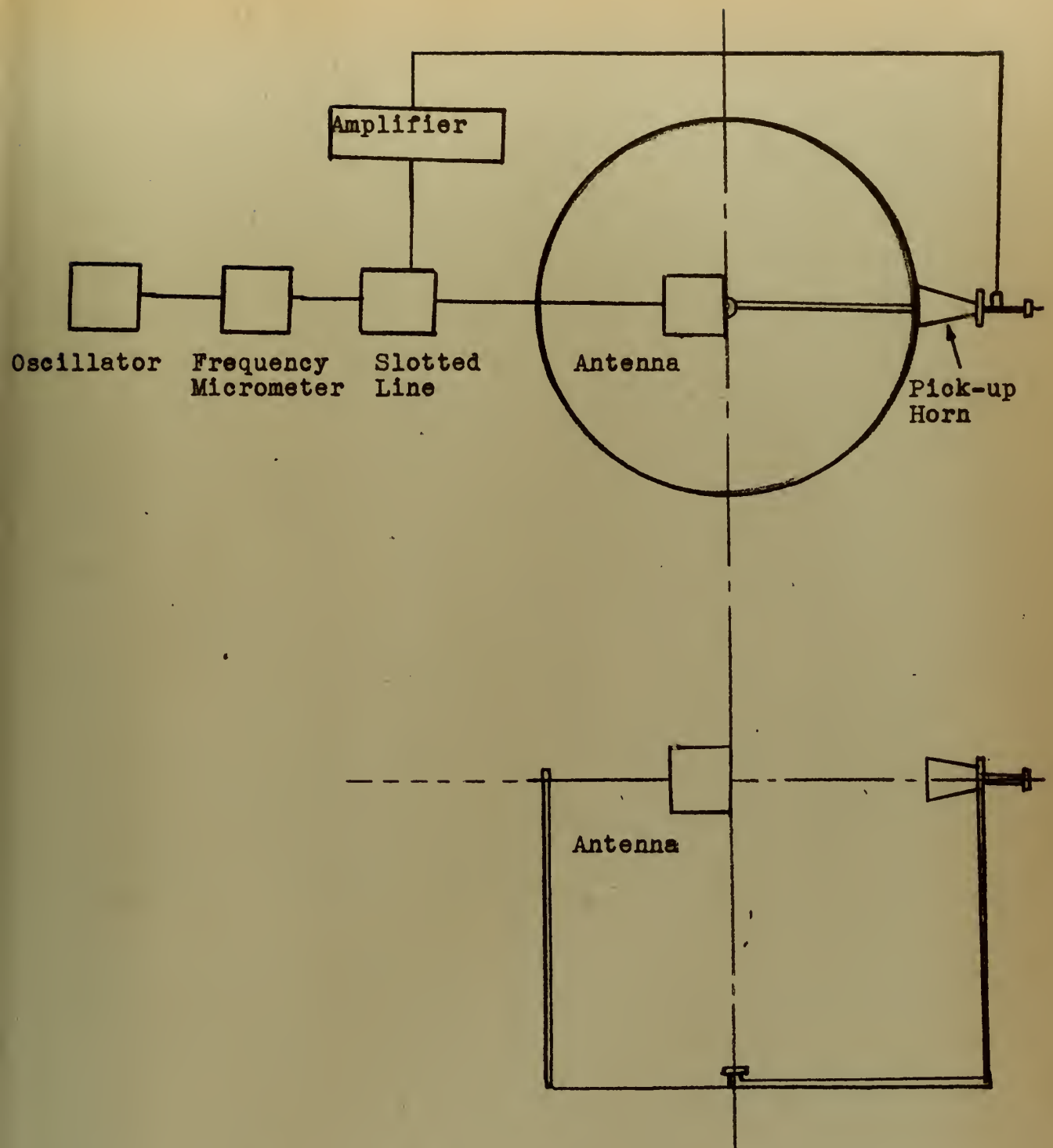plane by means of an accurately controlled turntable. A

18

Figure 7. Block Diagram of Measuring Equipment

19

vernier on the turntable permits reading the angle offset to 0.1 degree. The end of the helix is directly over the center of the turntable, i.e. on the vertical axis about which the turntable is rotated. The helix can also be rotated 360 degrees about its own axis to facilitate obtaining the axial ratio.

In both methods the receiving antenna is connected to a crystal mount and the signal sent to an amplifier where the voltage is read. The axial ratio is the ratio of the maximum to the minimum voltages read as the receiving antenna is rotated on its horizontal axis through 360 degrees.

The patterns presented in this investigation were obtained in an anechoic chamber and were measured in the planes of maximum and minimum radiation. These patterns were made at the mid-frequency and at the upper and lower ends of the prescribed bandwidth. In all measurements great care had to be exercised to align the axes very accurately.

CHAPTER V

EXPERIMENTAL PROCEDURE

The physical dimensions of the helix at K band are so
small that some means of support must be provided for proper
rigidity of the helical structure. It was decided to wind
the helix on a polystyrene form, i.e. a cylindrical rod
threaded for the desired pitch and helix diameter. Poly-
styrene was selected because of its low dissipation factor.
It is also relatively easy to machine. A helix wound on
such a rod operates in two mediums, polystyrene within the
helix and free space without. Thus a shell is employed to
surround the form such that the helix is embedded in a con-
tinuous medium of known dielectric constant. The dimensions
of the helix are therefore $1/\sqrt{\epsilon}$ times the free space dimensions,
where ϵ is the dielectric constant of polystyrene. If the
shell is made to extend over the end of the helix excessively,
it tends to act as a dielectric rod antenna, and thereby to
restrict the beamwidth of the radiation pattern. It can also
effect the axial ratio by causing a poor match at the end of
the helix. A poor match produces a reflected wave, opposite-
ly polarized, and traveling towards the feed end. The great-
er the magnitude of the reflected wave, the higher the axial
ratio. Experiment shows that extending the shell approximate-

21

ly $2S_\lambda$ over the last turn of the helix gives satisfactory
results.

Several attempts were made to feed the helix by a simple
probe into the waveguide. A circular ground plane was sol-
dered on the broad side of the waveguide. The cylindrical
rod on which the antenna was wound was fitted snugly into
a hole through the center of the ground plane and the wave-
guide's wall. The probe was led coaxially through this hole
and coupled to the E field in the guide. A tuning stub ter-
minated the guide approximately ten wavelengths from the
probe. Various arrangements were made with this feed and
some successful patterns resulted. However, it was found
that duplicating the characteristics of an antenna was vir-
tually impossible since the position of the probe was so
critical. Any slight bend in the probe or variation of
depth caused considerable differences in the radiation pat-
tern. This same undesirable condition prevails when the
helix is grounded to the waveguide, and also when a loop
type feed is employed. A great deal of time was spent in
trying to get consistency in readings taken between various
antennas which were supposedly the same. It finally became
apparent that it was not possible to manufacture two antennas
having the same characteristics when a probe or loop pick-up
was used.

Next the feed was altered by eliminating the probe and simply extending the helix into the waveguide. This is very similar to a method employed to energize the helix in a traveling-wave tube [14]. The radiation pattern was very dependent upon the orientation and depth of the helix into the guide, but the results were reproducible from one antenna to another. The difficulty in this method is the frequency sensitivity. As the frequency was varied it was necessary to retune the adjustable short terminating the waveguide in order to obtain the desired characteristics.

Finally it was decided to use an end-fire feed system, extending the helix into the end of the waveguide, and thereby eliminate the tuning stub. A wave traveling towards the end of the waveguide is picked up by the helical feed and this initiates a propagating wave on the helical structure. Once again the depth of the helix into the waveguide effects the characteristics, but three turns was selected as the optimum and the results were found satisfactory. This agrees with a statement by Haycock and Ajioka [2] that at least three turns are necessary to obtain circular polarization. A bandwidth of 600 megacycles was required and easily obtained using this feed. Figure 8 shows the construction of the antenna. A polystyrene tapered section was added to improve the match of the antenna to the waveguide.
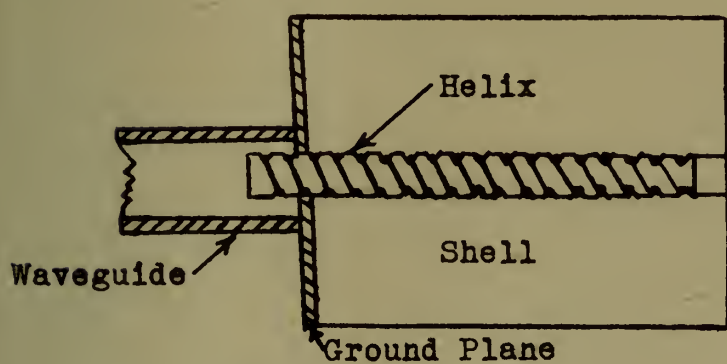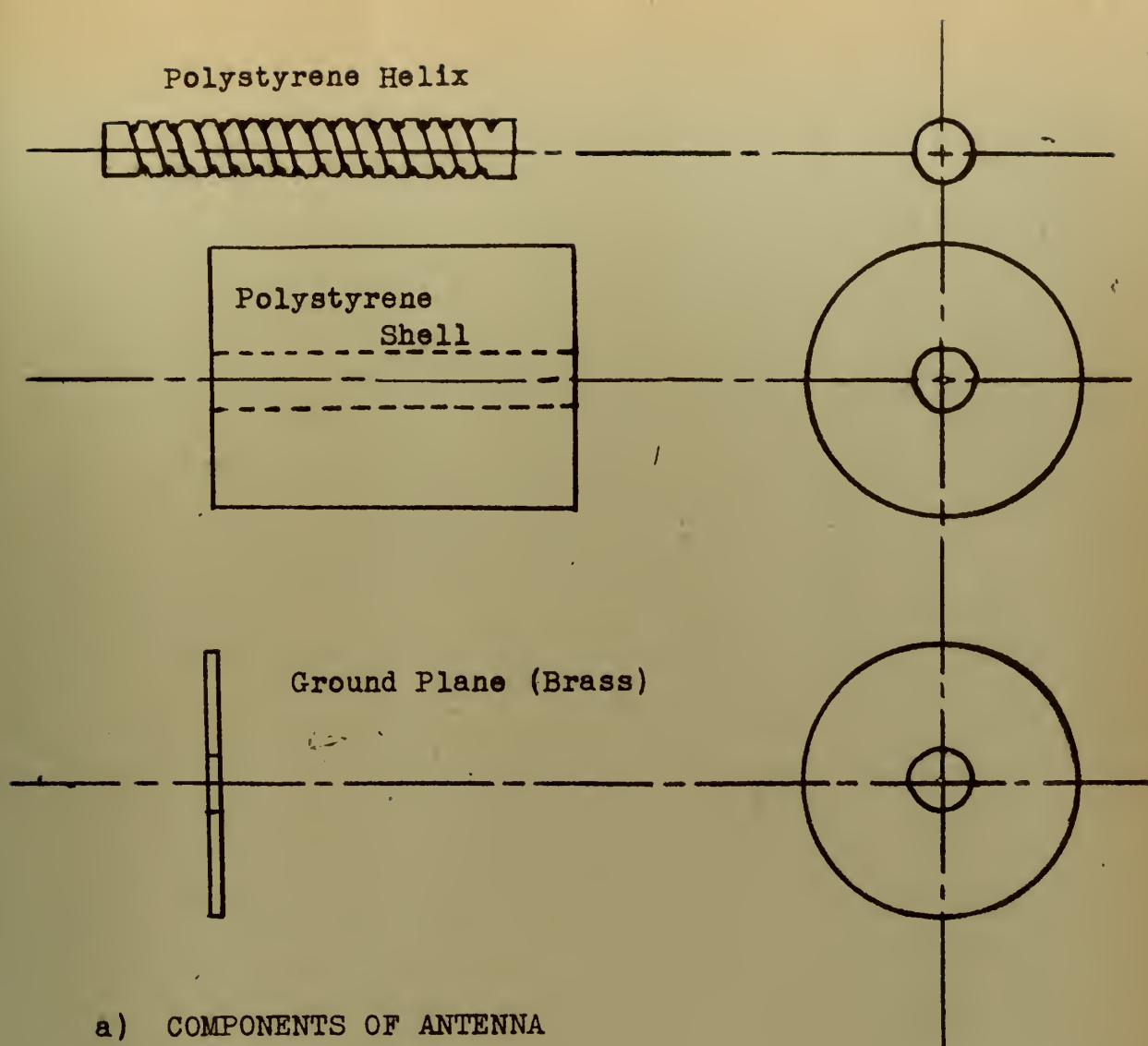
Polystyrene Helix

Polystyrene
Shell

Ground Plane (Brass)

a) COMPONENTS OF ANTENNA

Helix

Waveguide

Shell

Ground Plane

b) ANTENNA ASSEMBLED

Figure 8. K Band Antenna Assembly

24

Results show that the position of the ground plane is extremely critical. It is necessary to have the ground plane exactly perpendicular to the end of the waveguide. Orientation of the helix within the waveguide is also critical since, for a given depth, the axial ratio and match very as the helix is rotated on its axis. This fact is not mentioned in the literature on traveling-wave tubes or helical structures, therefore curves are presented in Figure 9, which show for a constant depth of three turns into the waveguide plots of orientation versus VSWR in the waveguide and axial ratio to two significant figures. It is interesting to note that at one angle, and 180 degrees from it, the polarization is essentially linear, and the VSWR is very high. The angle indicated on the abscissa is that between the top of the waveguide and the end turn of the helix, going clockwise as the antenna is viewed outside the waveguide. The helix itself is a right-hand winding.
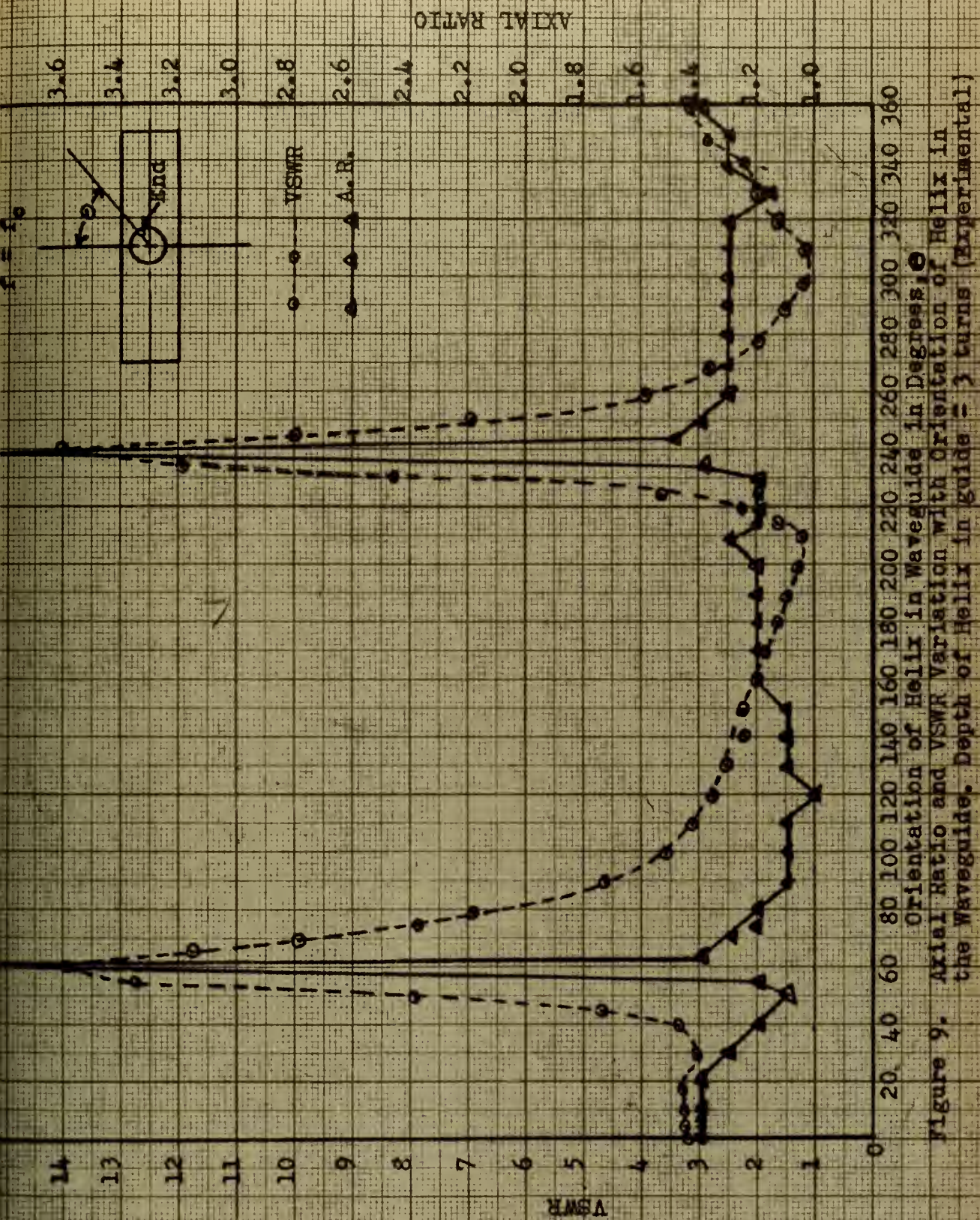
Figure 9. Axial Ratio and VSWR Variation with Orientation of Helix in the Waveguide. Depth of Helix in guide = 3 turns (Experimental)

26

CHAPTER VI

THE EFFECT OF MATCH ON AXIAL RATIO

Considering the results shown by Figure 9, it appears reasonable to expect the match and axial ratio to become poor simultaneously. Again referring to an early section of this paper, the reflected wave returning to the feed end of the helix is of such magnitude as to make the axial ratio very large. This same wave will effect the match at the input resulting in a large VSWR in the waveguide. This accounts for the magnitude of the axial ratio within the waveguide. Since the helical antenna external to the guide receives its wave from the feed, the radiation pattern is also effected. This may be explained by assuming the following method of propagation.

Assume that a right-hand circularly polarized wave is launched along the helix inside the waveguide and call it E_{R1}. (A right-hand wave results since the helix is wound in this direction.) When this wave reaches the ground plane a reflection occurs and an oppositely polarized wave, E_{L1}, travels back along the helix to the input end. The magnitude of E_{L1} depends on the amount of mismatch the ground plane presents to the first three turns of the helix. At the ground plane a wave continues along the helix external

to the waveguide which will be designated as E_{R2}. The ellipticity of E_{R2} is given by the expression

$$A.R._{E_{R2}} = \frac{E_{R1} + E_{L1}}{E_{R1} - E_{L1}}.$$

As E_{R2} travels along the external helix it causes a reflected wave, E_{L2}, at the end. Neglecting second and higher order effects, (i.e. multiple reflections) the waves present on the helix external to the ground plane are E_{R2} and E_{L2}. Thus the axial ratio of the radiated wave may be expressed as

$$A.R. = \frac{E_{R2} + E_{L2}}{E_{R2} - E_{L2}}.$$

The reflection of E_{R2} at the end of the helix causes E_{L2}. Since the reflection occurring at the end of the helix remains essentially independent of the orientation of the helix, E_{L2} may be expressed as equal to kE_{R2}, where k is a constant involving the reflection coefficient and the attenuation factor of E_{R2}. Therefore the axial ratio of the radiated field may be expressed as

$$A.R. = E_{R2} \frac{1 + k}{1 - k}.$$

This shows that the axial ratio is a function of the ellipticity of E_{R2}, which in turn depends on the match within the waveguide.

Let the reflection which occurs within the guide be
designated as R. This total reflection is the sum of at
least three components (by neglecting second or higher order
reflections). The first is due to the feed end of the helix;
the second is due to the ground plane; and the third is due
to the end of the external helix. The reflection occurring
at the feed end of the helix will be designated as r_1, a
constant which depends on the coefficient of reflection at
that particular point. Reflections r_2 and r_3 are similarly
defined for the ground plane and the end of the external
helix respectively. The angle, Θ, is defined as the angular
rotation of the E-vector from the E-vector position in the
guide along the helix to the reflection boundary in question.
The reflection in the guide may be written as

$$R = r_1 e^{-j\Theta_1} + r_2 e^{-j\Theta_2} + r_3 e^{-j\Theta_3}$$

where the subscripts refer to the above given positions
along the helix. Reflection r_3 is constant, however r_1
and r_2 vary as the helix is rotated. The variation of r_1
and r_2 may be explained in terms of the planes in which they
occur. The position of the end of the conductor in the guide
effects r_1 whereas the position of the conductor in the
aperature of the ground plane determines r_2. Thus it would
appear that the effective value of R depends on the helix

29

orientation and so determines the axial ratio of the radiated
field.

CHAPTER VII

RESULTS AND CONCLUSIONS

The antenna's characteristics are shown in Figures 10 through 13. Figure 10 is the radiation pattern at the center frequency, Figure 11 at 300 megacycles above center frequency, and Figure 12 at 300 megacycles below center frequency. These patterns were taken in an anechoic chamber. The beamwidth between half-power points is 23 degrees over the bandwidth. These patterns compare very well with low frequency helical antenna patterns. The axial ratio is less than 1.25 within the beamwidth over the frequency band. The axial ratios may be determined from the patterns by taking the ratio of the magnitudes of the field intensities at any given point on the pattern.

Figure 13 is a Smith chart plot of impedance versus frequency for the helical antenna at K band. The impedance is relatively constant over the bandwidth. Two extreme points of frequency are plotted which show the tendency for the plot to spiral on itself as has been observed for low frequency helical antennas $\boxed{10}$. The impedance is of the same order of magnitude as for low frequency antennas and almost pure resistance (a ratio of R to X of almost 12 to one) at the center frequency. A measure of true impedance
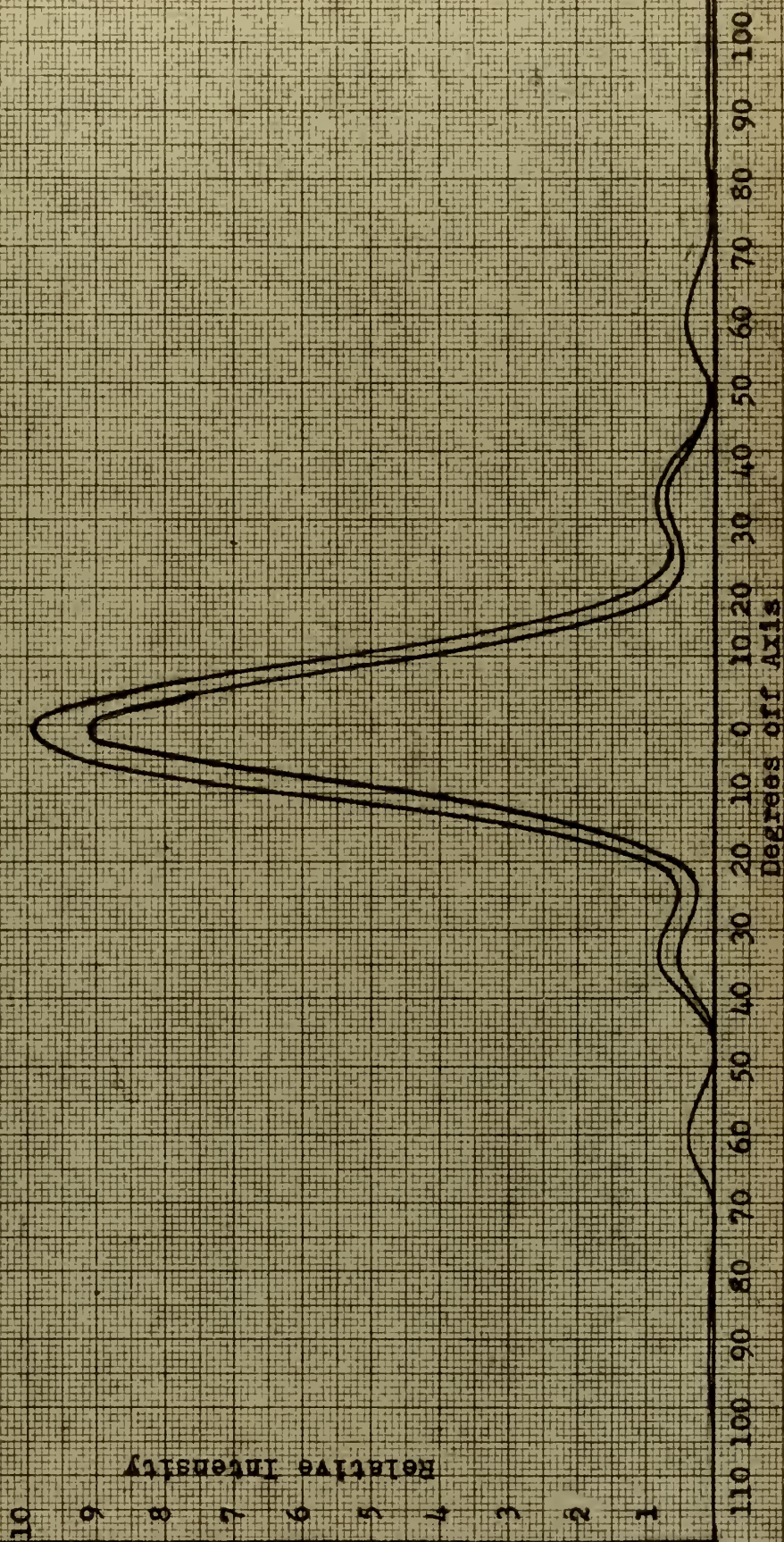
31

Figure 10. Measured Radiation Pattern at Center Frequency, f_0

$f = f_0$

A.R.$_0$ = 1.10

Degrees off Axis

Relative Intensity

32
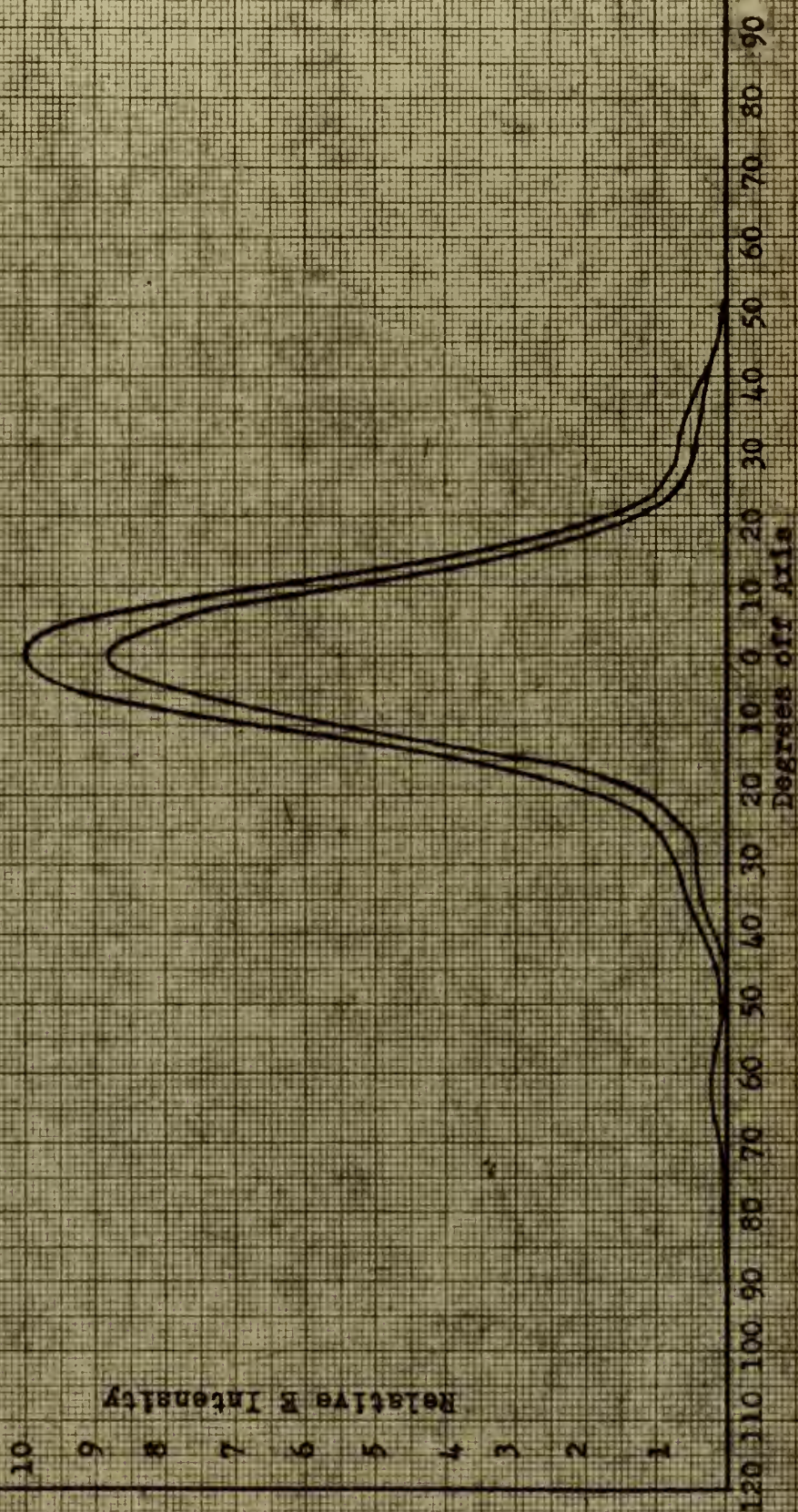
Figure 11. Measured Radiation Pattern at Center Frequency plus 300 Megacycles

$f = f_0 \neq 300$ mcs

A.R.O = 1.14

Relative E Intensity

Degrees off Axis

33

$f = f_0 = 300$ mos

$A.R._0 = 1.07$

Degrees off Axis

Relative E Intensity
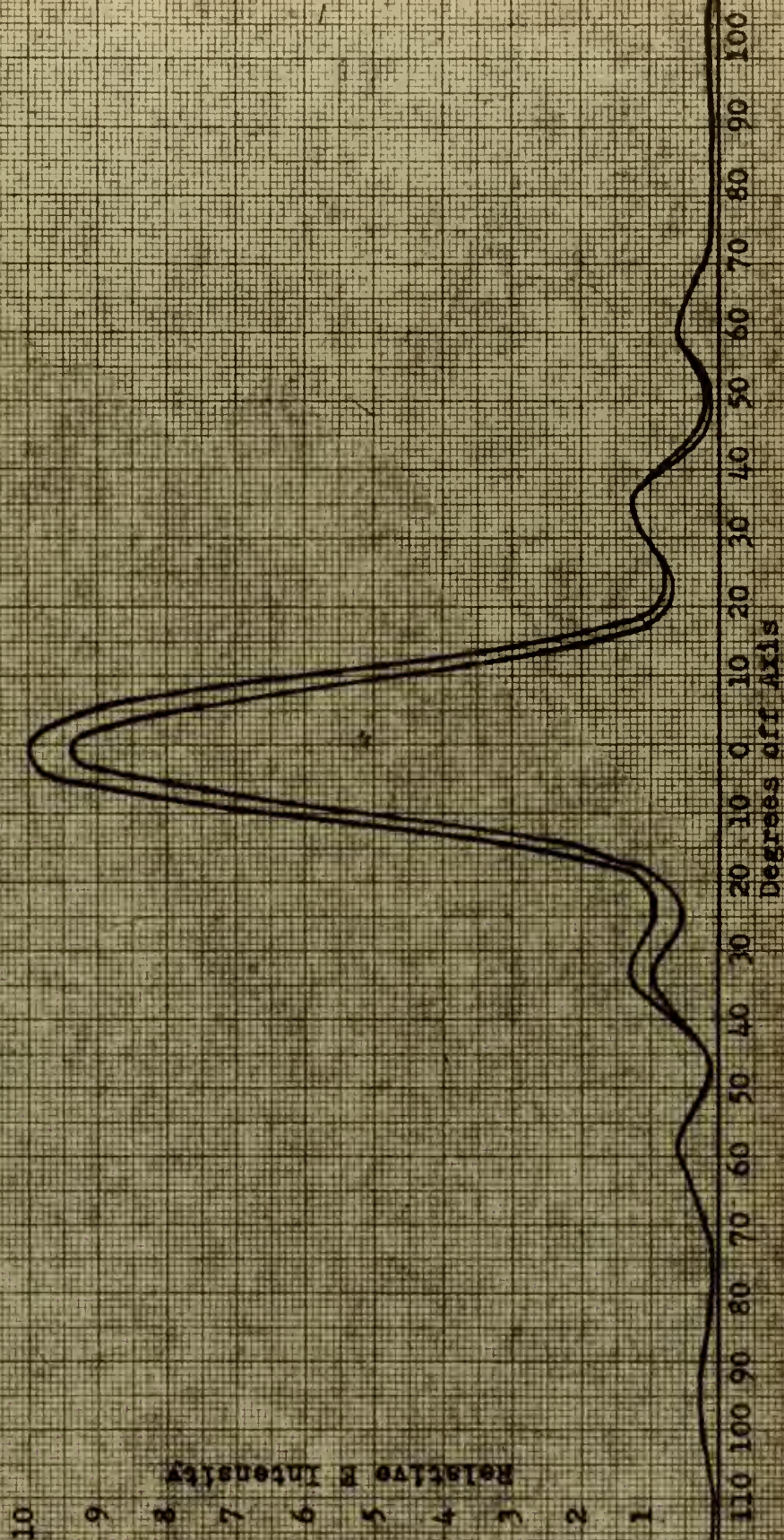
Figure 12. Measured Radiation Pattern at Center Frequency Minus 300 Megacycles.

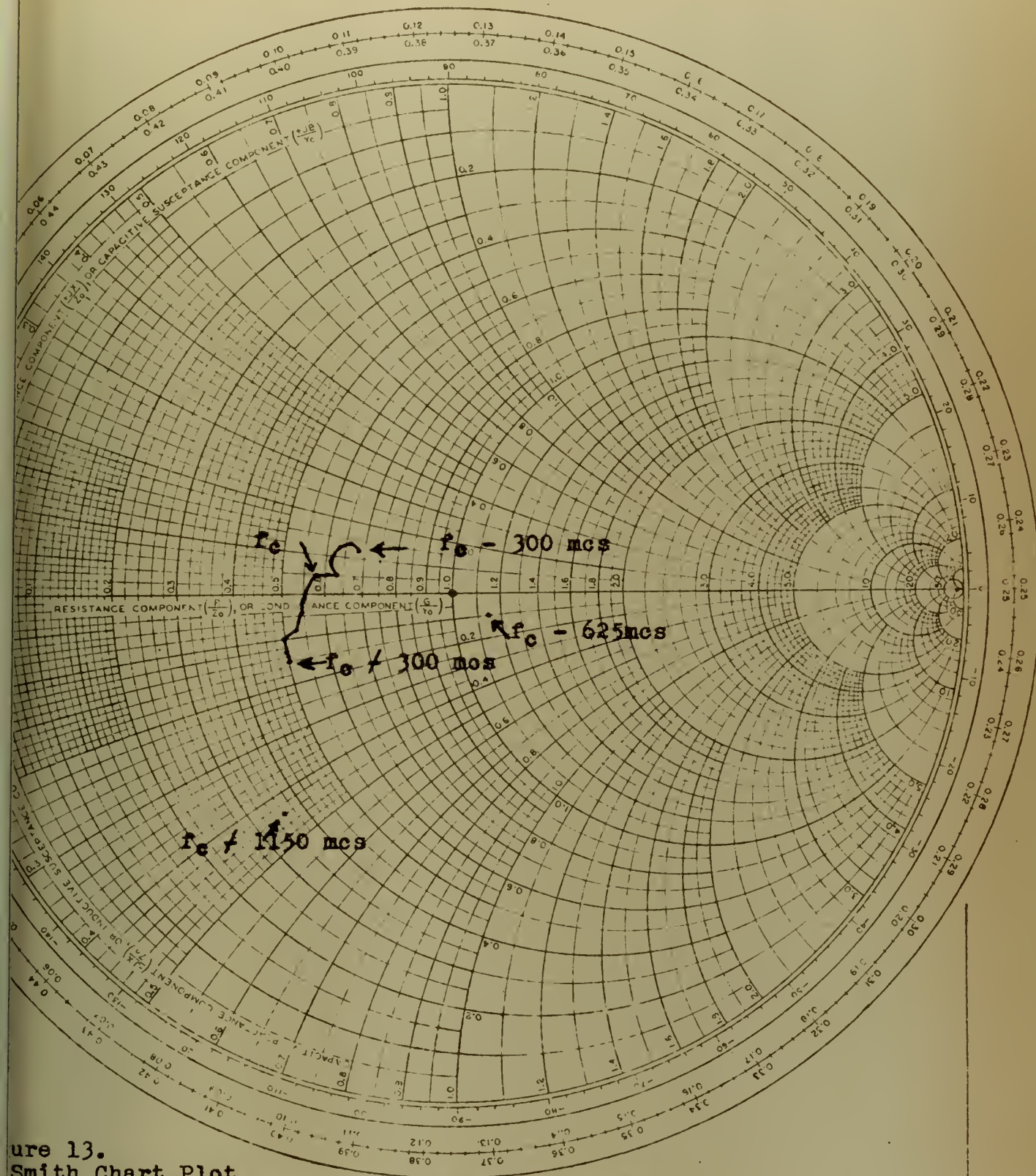34

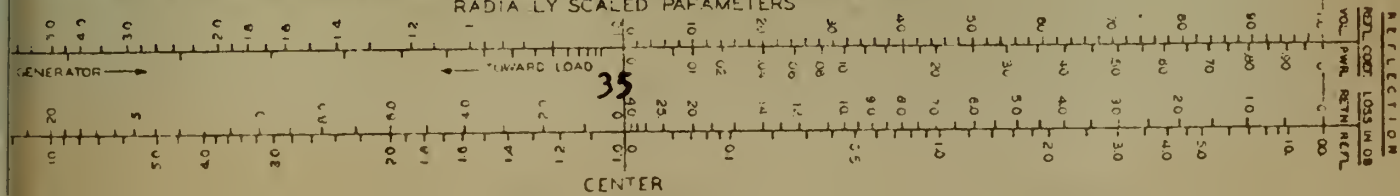## IMPEDANCE OR ADMITTANCE COORDINATES

Figure 13.
Smith Chart Plot
of K Band Antenna over Prescribed Bandwidth

RADIALLY SCALED PARAMETERS

is difficult because of the polystyrene surroundings and the inability to determine how much of the observed phase shift is due to the helix alone. The observed VSWR in the waveguide was less than 2.0 over the bandwidth.

The helical antenna at K band is feasible and possesses the inherent advantages of a low frequency helical antenna. Extreme precautions must be taken as is to be expected for the microwave spectrum. The most serious problem is that of matching the helix to the waveguide in order to launch a wave on the helix, and this problem is overcome by careful orientation of the helix within the guide as shown in this investigation.

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The following expressions were developed by Sollfrey $\underline{/15\_7}$
to give the transverse fields on the helix in rectangular
coordinates.

$E_x(0,z) =$

$$\frac{-I\csc\alpha}{4\pi}(\mu/\epsilon)^{\frac{1}{2}}\left[\left\{p_1K_1(p_1a)-k\cos\alpha K_0(p_1a)\right\}e^{ikz\csc\alpha(1-1/ka\sec\alpha)}\right.$$

$$\left.\neq\left\{p_{-1}K_1(p_{-1}a)\neq k\cos\alpha K_0(p_{-1}a)\right\}e^{ikz\csc\alpha(1\neq 1/ka\sec\alpha)}\right]$$

$E_y(0,z) =$

$$\frac{-iI\csc\alpha}{4\pi}(\mu/\epsilon)^{\frac{1}{2}}\left[\left\{p_1K_1(p_1a)-k\cos\alpha K_0(p_1a)\right\}e^{ikz\csc\alpha(1-1/ka\sec\alpha)}\right.$$

$$\left.-\left\{p_{-1}K_1(p_{-1}a)\neq k\cos\alpha K_0(p_{-1}a)\right\}e^{ikz\csc\alpha(1\neq 1/ka\sec\alpha)}\right]$$

where K_1 and K_0 are Bessel functions and p_n is given by:

$$p_n^2 = \left[(n/a\tan\alpha)-k\csc\alpha\right]^2 -k^2 \quad \text{with } k = \omega\sqrt{\mu\epsilon}$$

$I =$ total current carried by the wire

$i^2 = -1$

$\alpha =$ pitch angle of helix

$\epsilon =$ dielectric constant

$\mu =$ permeability

For ease in manipulation the following substitutions are made:

Let

$$A = \frac{-I\csc\alpha}{4\pi}(\mu/\epsilon)^{\frac{1}{2}}$$

$$B = p_1K_1(p_1a) - k\cos\alpha K_0(p_1a)$$

$$C = p_{-1}K_1(p_{-1}a) + k\cos\alpha K_0(p_{-1}a)$$

$$D = ikz\csc\alpha$$

$$E = ikz\csc\alpha/ka\sec\alpha$$

Then the equations may be expressed as:

$$E_x = A(Be^{D-E} + Ce^{D+E}) = Ae^D(Be^{-E} + Ce^{+E})$$

$$E_y = iA(Be^{D-E} - Ce^{D+E}) = iAe^D(Be^{-E} - Ce^{+E})$$

Thus

$$E_x + E_y = Ae^D \left[Be^{-E}(1+i) + Ce^{+E}(1-i) \right]$$

which shows that the field can be expressed as two circularly polarized waves of opposite polarization, unequal in amplitude, and traveling in opposite directions.

AG 29 56

4 4 6 7